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EFFECT OF QUENCHING RATE ON STRESS-CORROSION CRACK GROWTH RATES IN 2024-T4 ALUMINUM

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ABSTRACT

Stress-corrosion crack growth rates in double cantilever beam specimens of 2024-T4 aluminum quenched at two rates from the solution-treatment temperature were compared. The specimens quenched at the slower rate had the faster crack growth rate. This finding agrees with data from other studies in which intergranular corrosion susceptibility was determined by measuring percent loss in tensile strength of preexposed sheet tension specimens.

INTRODUCTION

When quenched at slow rates, 2024-T4 is prone to intergranular attack and may be susceptible to stress-corrosion cracking and exfoliation. Work performed by L. A. Willey using the interrupted-quench technique (1) established the temperature range during quenching in which the corrosion characteristics are established. The most critical changes in both corrosion characteristics and tensile properties were found to occur in the 750° to 550°F temperature range during quenching.

Willey (1) and Lifka and Sprowles (2) have measured the effects of quenching rate between 750° and 550°F on tensile properties and resistance to corrosion of 2024-T4 and 7075-T6 sheet specimens. Stressed (to 75% of yield strength) and unstressed sheet tension specimens of these two alloys that had been quenched at different rates were exposed to alternate immersion in 3.5% NaCl solution for 12 weeks. The specimens were then pulled to failure and the percentage loss in tensile strength for the various specimens determined. These data are presented in Fig. 1, along with the type of corrosion attack observed at the different quench rates. Studies by Mears, Brown, and Dix (3) and Hunter, Frank, and Robinson (4) explain this behavior based on localized electrochemical effects associated with the forma ion of grain boundary precipitates and adjacent depleted zone.

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The goal of the present study was to measure the effect of quench rate on actual stress-corrosion crack growth rates rather than on strength losses of preexposed tension specimens.

MATERIALS AND TEST PROCEDURES

Double cantilever beam (DCB) specimens of the configuration shown in Fig. 2 were used for this study. The advantages and use of this specimen in studying stress-corrosion cracking in high-strength aluminum alloys have been described by the author (5,6,7,8,9,10). By using this specimen and Eq. (1) (from Ref. 7), stress-corrosion crack growth rate data can be obtained as a function of plane-strain stress intensity K_I .

$$K_I = \frac{vEh\ [3h\ (a + 0.6h)^2 + h^3]^{1/2}}{4\ [(a + 0.6h)^3 + h^2a]} \qquad (1)$$

where: v = total deflection of the two arms of the DCB specimen at the load point (centerline of loading bolt).

E = modulus of elasticity (10.3×10^6 for aluminum alloys)

h = 1/2 specimen height

a = crack length measured from load point (centerline of loading bolt)

The procedure for obtaining the crack growth rate data is illustrated schematically in Fig. 3. The loading bolt is turned until a sharp crack is popped in from the end of the machined notch. Plane-strain fracture toughness K_{Ic} can be calculated from Eq. (1) by measuring v and a at any subsequent pop-in. After the crack has been advanced a few tenths of an inch by several pop-ins, the bolt is left fixed, giving a constant crack opening displacement (COD), and the 3.5% NaCl environment is applied. Under these conditions the load P at the bolt and K_I at the crack tip decrease as the stress-corrosion crack length increases (Figs. 3b and 3c). The slope of the resulting crack

length-time curve in Fig. 3a then gives the crack growth rate as a function of K_I. As the crack length a increases and K_I decreases, a K_I level may eventually be reached below which growth ceases or is negligible. This K_I level, designated K_{Iscc}, is shown in Fig. 3c. Use of this technique is especially suited to aluminum alloys with elongated grain structures, since stress-corrosion cracking is intergranular and cracks are kept in plane by the elongated grain structure of the material.

For this study two DCB specimens were machined from 1-in.-thick 2024-T351 plate. The specimens were re-solution treated, quenched into either cold water (75°F) or water at 150°F, and naturally aged to the T4 temper. Average quenching rates between 750° and 550°F were calculated from Fig. 14 in Ref. 2 to be 330°F/sec and 80°F/sec for the two quenching conditions.

Both specimens were bolt loaded to K_{Ic} and the steel bolts were insulated by masking the bolt end of the specimens with a vinyl coating. The specimens were then placed upright (bolt end up) and, using a polyethylene squeeze bottle, several drops of an aqueous solution of 3.5% NaCl were placed in the machined notch of the specimens. The NaCl solution was applied three times each working day at 4-hr intervals. Crack lengths were monitored using a hand lens and ruler.

RESULTS AND DISCUSSION

The stress-corrosion crack growth rates for the two specimens are shown in Fig. 4. The more slowly quenched specimen shows a growth rate 1.6 to 4 times faster than that for the more rapidly quenched specimen at equivalent K_I levels.

Previous work (9) has shown that quenched-in residual stresses in re-heat-treated DCB blanks such as were used in this study cause errors in K_I calculations based on Eq. (1). The errors result from geometry changes in the arms of the DCB specimens as the stress-corrosion crack propagates through the specimen. Residual compressive stresses on the surfaces of the specimen cause the two arms to bow apart slightly as the crack grows and relieves the residual tensile stresses inside the

specimen. This effectively increases the COD at the crack tip and makes K_I higher than calculated with Eq. (1). Thus, the K_I-rate (K_I versus crack growth rate) curves for these specimens with residual quenching stresses should be moved to the right in Fig. 4. However, the curve for the cold-water-quenched specimen should be shifted further to the right, since that specimen has the higher residual quenching stresses and therefore the greater error in calculated K_I. Shifting the curves in Fig. 4 as described would only increase their separation. Therefore, despite the residual stress problem with these re-heat-treated and quenched DCB specimens, it can be concluded from Fig. 4 that stress-corrosion crack growth rates for 2024-T4 increase with decreasing quench rate. The mechanism for the increased crack growth rate is most certainly the same as that found responsible for increased susceptibility to intergranular attack and increased loss in tensile strength of 2024-T4 aluminum after preexposure, namely, the precipitation of copper-rich phases along grain boundaries during slow quenching with subsequent depletion of copper adjacent to grain boundaries (3). This gives rise to a difference in solution potential between the two areas, creating an anodic path in the copper-depleted regions adjacent to the boundary.

CONCLUSIONS

Slow quenching rates for 2024-T4 increase susceptibility to intergranular attack and increase the growth rate of actual stress-corrosion cracks.

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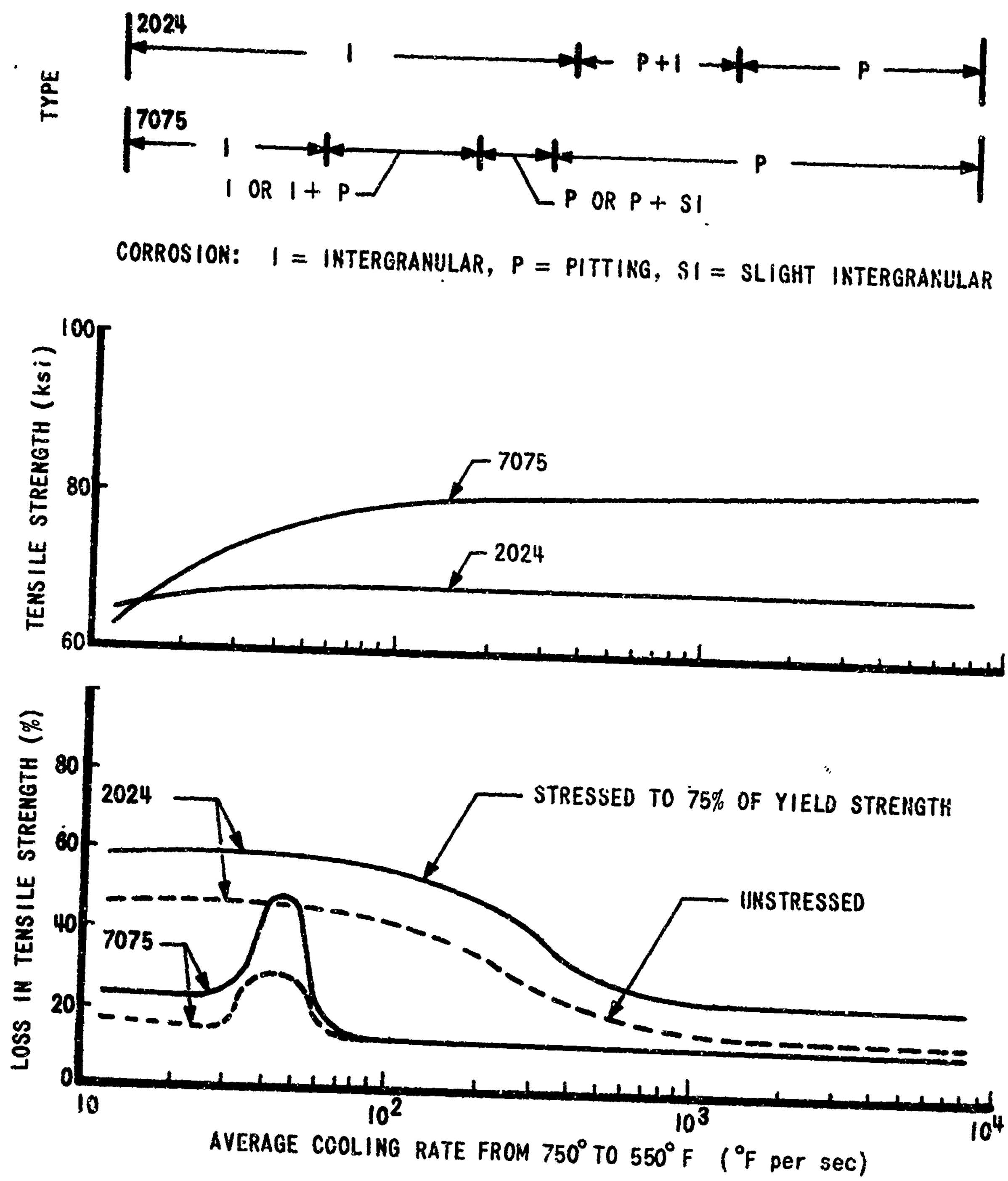
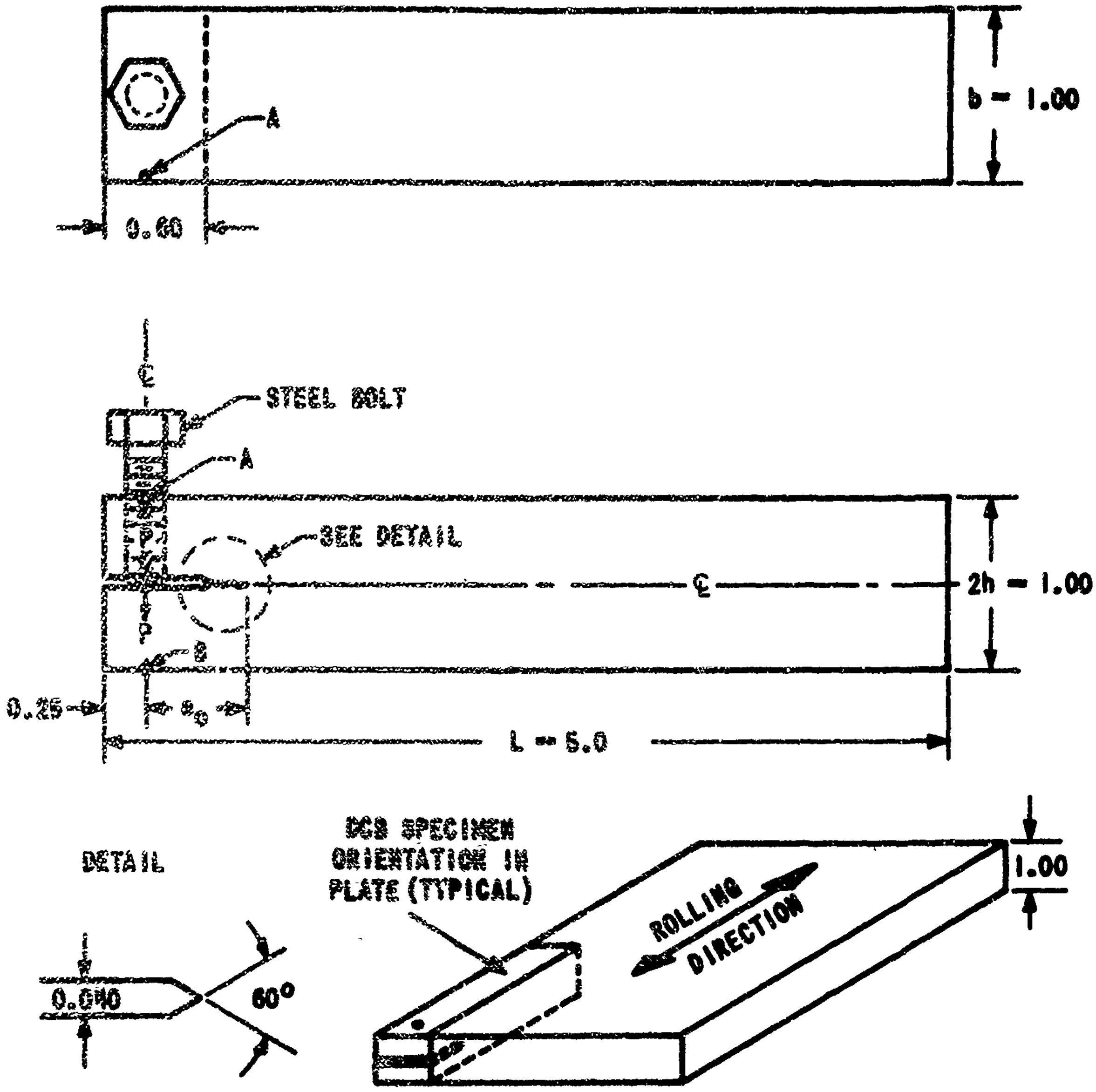


Figure 1 *Effects of quenching rate on tensile properties and corrosion resistance of 2024-T4 and 7075-T6 sheet. Stressed and unstressed specimens were exposed to alternate immersion in 3.5% NaCl solution for 12 weeks before testing (from Ref. 2).*



CRACK OPENING DISPLACEMENT v EQUALS THE MEASURED DEFLECTION BETWEEN POINTS A AND B ALONG THE BOLT CENTERLINE

Figure 2 *Double cantilever beam specimen used for stress-corrosion testing of high-strength aluminum alloys.*

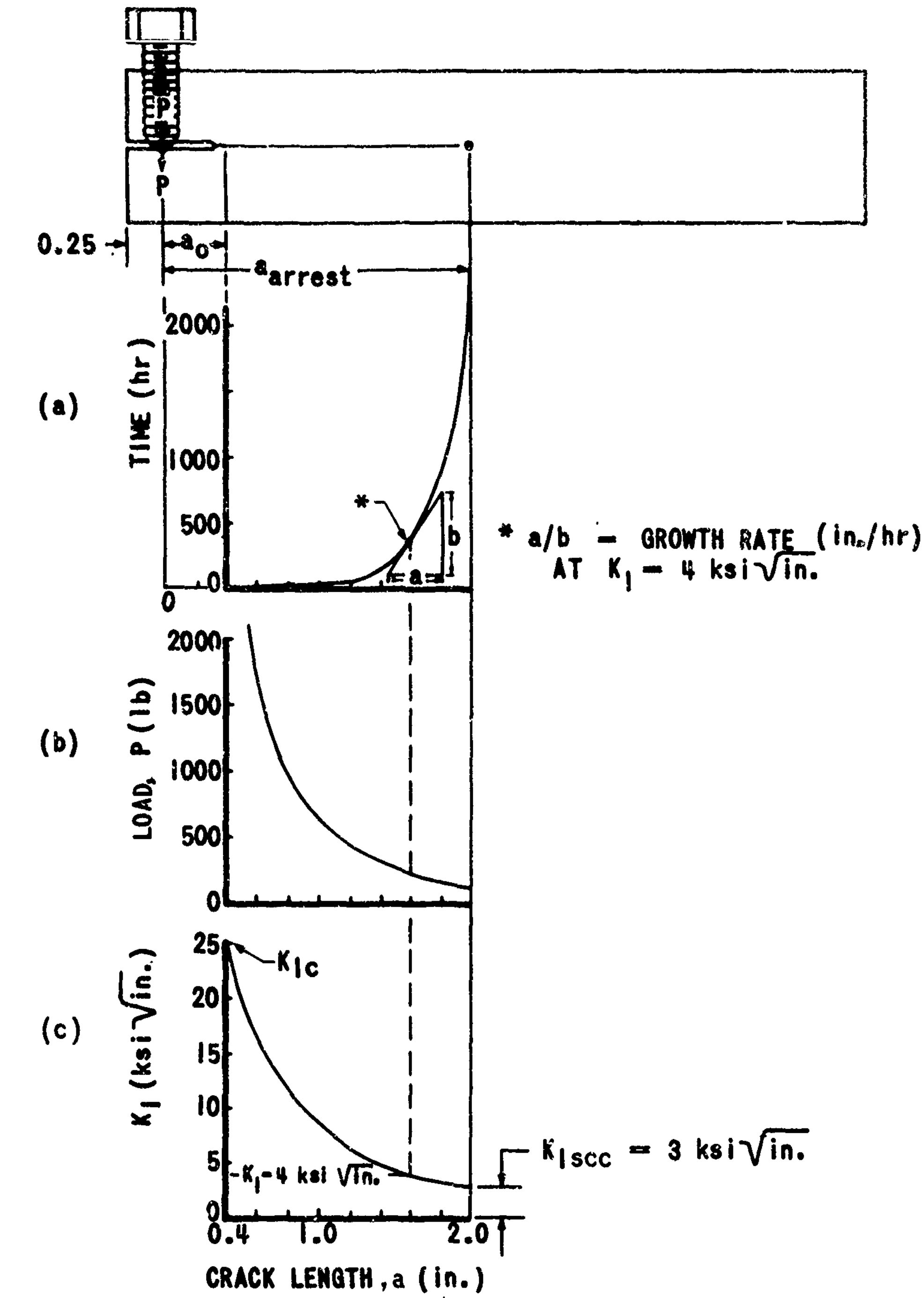


Figure 3 *Effect of crack growth on load and stress intensity under constant crack opening displacement conditions (v = 0.010 in.) in a 1- by 1- by 5- in. aluminum-alloy DCB specimen.*

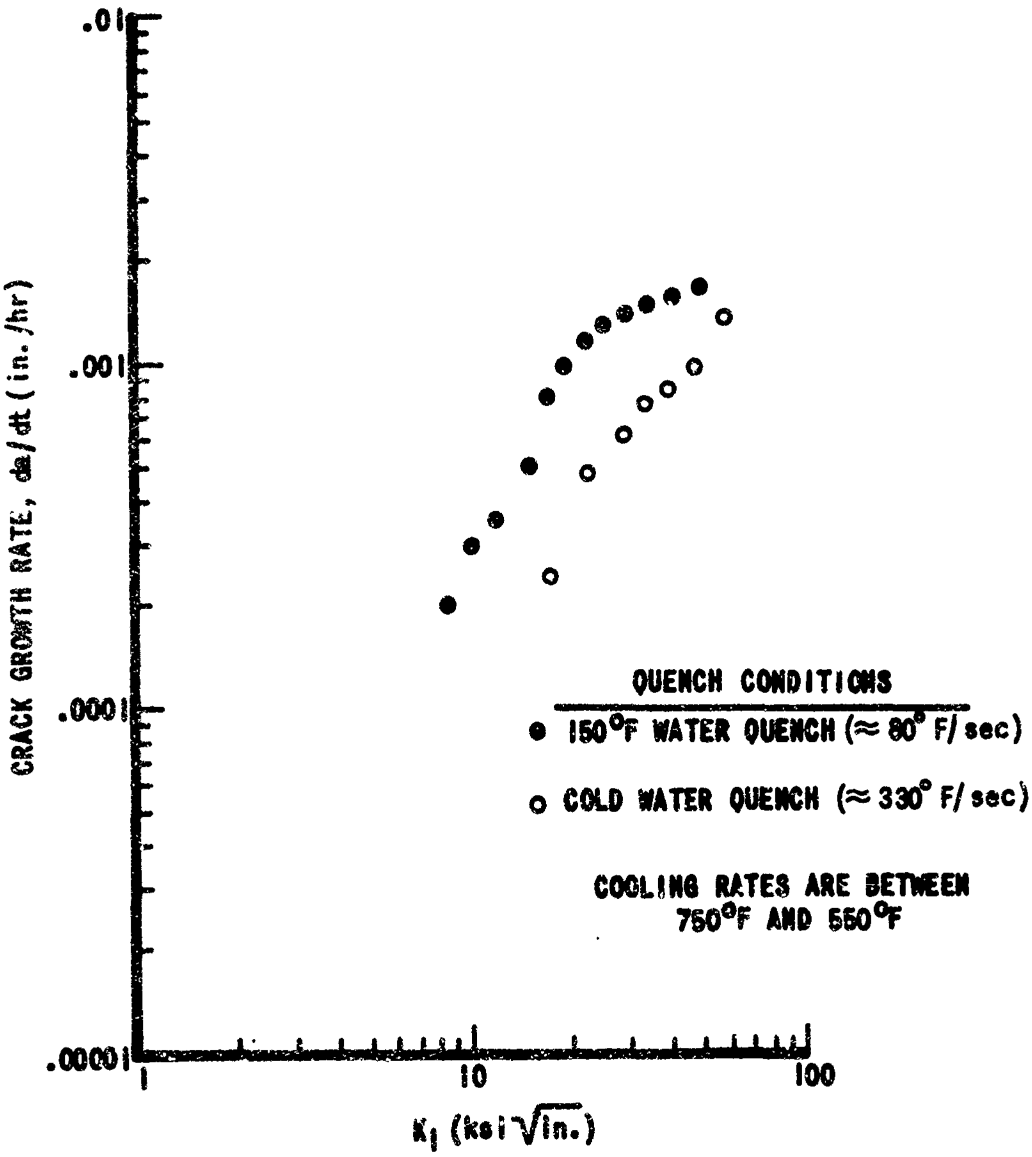


Figure 4 *Effect of quenching rate on K_I-rate data for reheat-treated 2024-T4 DCB specimens from 1-in.-thick plate.*

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Quenching Rate						